Appendix 6

How Does Water Price Affect Irrigation Technology Adoption?

The $\delta^{15}N$ values at most sites were fairly consistent with depth from the surface to the water table. There is no evidence from our data that denitrification is a significant process at any of the sites, with the possible exception of the Salinas Valley septic tank site. Thus, except for one site in the eight main test sites, the results demonstrate that measuring the $\delta^{15}N$ value immediately below the NO_3 source can be an accurate indicator of the fingerprint of that source and that, under the conditions prevailing at these sites, the fingerprint will not change much during NO_3 transport to groundwater. This is a very important conclusion for use of the N isotope technique to indicate sources of NO_3 in groundwater. Nevertheless, users of the $\delta^{15}N$ approach should be aware of the potential for mixing of $\delta^{15}N$ from multiple sources and of denitrification under some circumstances. Careful hydrogeologic characterization as well as sampling of both the unsaturated and saturated zones beneath potential sources are therefore typically required for successful application of the $\delta^{15}N$ approach.

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How does water price affect irrigation technology adoption?

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The use of water price or best management practices have been advocated by some commentators to induce adoption of low-volume irrigation technologies and to encourage water use efficiency. However, the method of water application is only one of many inputs and constraints in agricultural production. California's highly diverse topography, soil types and variety of crops influence irrigation technology choices, therefore a policy mandating adoption of modern technologies is likely to have undesirable impacts. Crop type appears to be a major consideration in technology choice, as some technologies may be incompatible with some types of crops.

Continued urban population growth, heightened public awareness of the environmental benefits of in-stream water flows, and the virtual halt of water supply development in California have increased pressure on state and federal agencies to reallocate water away from agriculture. Many public-interest groups and policy makers have suggested that growers could increase their use of low-volume irrigation technologies while maintaining current production levels. Some interests have even advocated imposing agricultural "best management practices" mandating the adoption of irrigation technologies. California growers have been criticized for their "irrational" and "inefficient" irrigation technology choices. It has been suggested that growers could maintain or increase their profitability while using fewer resources. In this article, we assess whether technology choice is consistent with the assumption of profit maximization and, if so, determine which factors most influence technology choice.

Some commentators have advocated the use of water price as a policy tool to induce adoption of low-volume irrigation technologies and to encourage increased water-use efficiency. Specifically, environmentalists and many economists frequently assert that irrigation water should be priced to encourage adoption of modern technologies and reflect the value of water outside agriculture. However, the effectiveness of water price to achieve these goals may be limited because the method of water application is only one of many crucial inputs and constraints in agricultural production.

Our model demonstrates that large increases in the price of water generally encourage heavier reliance on drip and other low-pressure irrigation systems for certain crops, but may have only modest effects on adoption decisions for other modern irrigation technologies.

Irrigation decisions in Arvin

We selected the Arvin Edison Water Storage District, located in the southern San Joaquin Valley at the terminus of the Friant-Kern Canal, as our study area. There is wide variation in the types of irrigation technologies employed in the District: 25% furrow or flood, 49% high-pressure sprinkler and 26% low-pressure drip and microsprinkler (table 1). This variation makes the District ideal for analysis because there is a large amount of variability, yet the area is relatively

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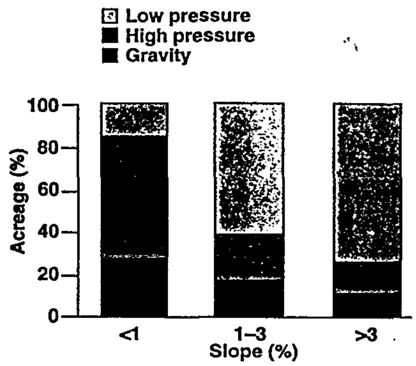


Fig. 1. Irrigation technology by slope.

than groundwater pumping costs. Growers in the District pay a relatively high variable price for water. In 1993 the price ranged from $12 to $57 per acre-foot for surface water and from $40 to $88 per acre-foot for groundwater. However, the District adjusts the fixed fee for surface water so that the total price for ground and surface water are approximately the same, ranging from $50 to $110. The price of both ground and surface water in the District has increased since 1993.

The wide range of water prices in the District creates an ideal forum for analyzing the effect of price on irrigation technology choices. Table 2 shows that there is not a clear pattern of technology choice as water price increases from less than $30 to more than $75 per acre-foot. For example, low-pressure irrigation is used on 24% of the acreage that receives water at less than $30 per acre-foot. The acreage increases to 35% in the next price range, but falls to 14% for those acres that pay more than $75 per acre-foot of water. However, it is important to note that only 5% of the cultivated acreage in the District faces a water price of more than $75 per acre-foot, so this has only a small effect on our results.

Soil permeability and field slope are the two dimensions used to define land quality. These data were collected from the Kern County office of the U.S. Natural Resource Conservation Service. The data provide soil type for each quarter section. District land maps were used to place each field in the corresponding quarter section. Permeability and slope were given in inches per hour and percent, respectively. Both permeability and slope were given in ranges; the midpoint was taken and used to construct weighted averages for each quarter section.

Figure 1 shows the distribution of irrigation technology for given slope ranges. Note that as slope increases the percent of acreage under low-pressure irrigation also increases. This indicates that the grower's irrigation technology choice is conditioned on land characteristics. The effect of permeability on technology choice is not as distinct.

These data are used with a statistical model of technology adoption. The crops, irrigation technology and agronomic diversity of the District are especially well suited to give insight into the constraints that growers face when responding to water policy.

TABLE 3. Effect of variable on probability of technology adoption

	Irrigation technology		
	Gravity	High–pressure	Low–pressure
Water price	–	–	+
Field size	–	+	+
Soil permeability	–	+	+
Field slope	–	+	+
Receive surface water	–	–	+
Crops			
Citrus	–	–	+
Deciduous	–	–	+
Grapes	+	–	+
Truck crops (including potatoes)	–	+	–

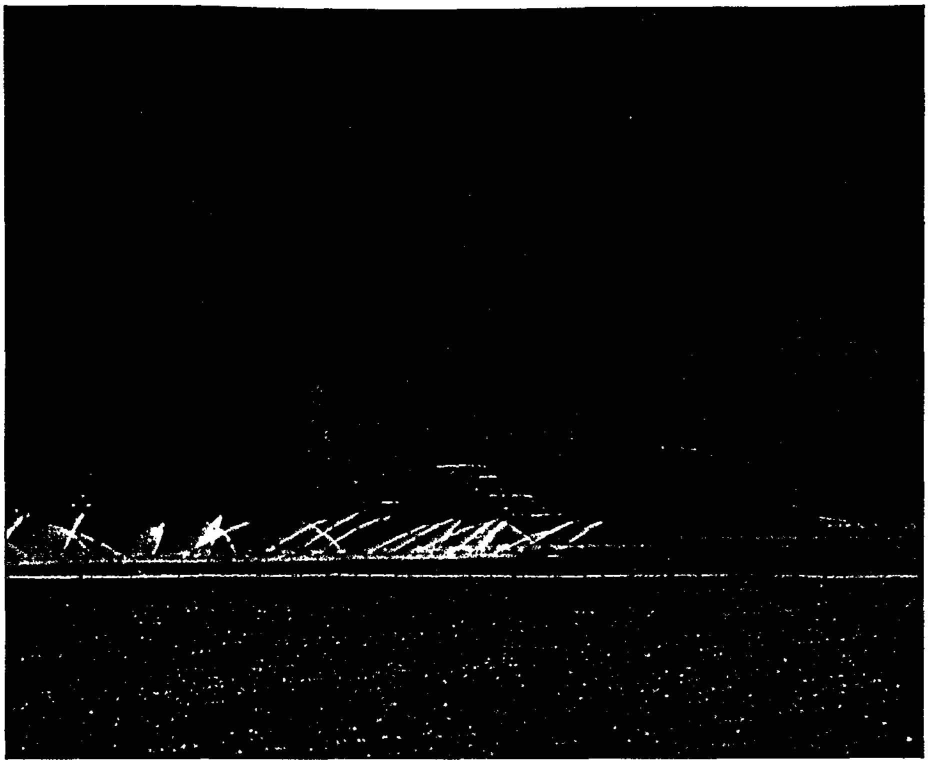
"+" indicated an increase and "–" indicates a decrease in the probability that the irrigation technology will be adopted.

Model results

The model predicts the probability that a given irrigation technology is adopted as a function of crop, land characteristics, water source and water price. The results in table 3 show whether a specific variable increases (+), decreases (–) or does not affect that probability of technology adoption.

The results indicate that the adoption of irrigation technologies is highly dependent on crop type. After controlling for field-specific factors, high-pressure systems are less likely to be adopted on all perennial crop (grapes, citrus and deciduous); low-pressure technologies are more likely to be adopted on all perennial crops (table 3). This finding can be attributed to the physical interaction between high-pressure sprinklers and perennial crops. High-pressure sprinklers disperse water over a large area, saturating the crop, which can cause disease in many perennial crops as well as some annual crops. Therefore high-pressure sprinklers are not used on some perennial crops. Under gravity irrigation, the results are less pronounced but still evident. This corresponds with the knowledge that many perennial crops can still be competitively grown with the traditional technology under the right growing conditions. However, we found that the choice to grow annual crops increases the probability of adopting high-pressure irrigation technologies.

The results also show that the adoption of low-pressure technology is highly sensitive to water price. This finding agrees with standard economic theory that water-saving technologies are adopted as the price of water increases. However, this does not hold true for high-pressure technology, which has a negative sign. In the study area, high-pressure irrigation has been in use since the late 1950s. Currently high-pressure irrigation is near the top of its diffusion curve; that is, it has been adopted on most crops that it can be productively used on. For example, potatoes are grown almost exclusively under high-pressure irrigation (table 1). As a result, the adoption of high-pressure irrigation is not sensitive to changes in water price in the District. Instead, the results indicate that growers have begun to switch from high-pressure to low-pressure irrigation. In fact, as the



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High-pressure sprinklers disperse water over a large area, which may make them a more desirable choice than a low-volume irrigation system for large fields.

more likely to be adopted as water price increases. Adoption of low-pressure systems is especially sensitive to water price in the District because there are many crops grown with gravity irrigation that can be grown with low pressure. In this case an increase in water savings, in addition to other benefits associated with low-pressure irrigation, may make adoption a cost-effective response to higher water prices.

The impact of changing how irrigation water is priced and delivered has an important distributional component. Whether or not a grower adopts irrigation technology in response to price increases depends on crop, topography and soil characteristics. However, using water price rather than best management practices as a policy tool allows growers flexibility in their response, which minimizes policy impacts. As a result, technology adoption that stems from changes in water-pricing policy will be gradual. This will minimize policy impacts because growers will be able to make the decision of when to adopt, depending on their own particular circumstances. Best management practices that dictate agricultural technology choices will have potentially large impacts on California growers. A policy that mandates when a given technology is to be adopted will probably be inefficient because it does not allow for the diversity among growers. Our results show that California's highly diverse climate and soil conditions influence irrigation technology choices, and a "one-size-fits-all" policy mandating adoption of modern technologies is likely to be highly inefficient.

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